

FORM PTO-1390		U.S. Department of Commerce Patent and Trademark Office	Attorney's Docket No. 2036-200
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371			U.S. Application No. (if known, see 37 CFR 1.5) 10/018460
INTERNATIONAL APPLICATION NO. PCT/NO00/00219	INTERNATIONAL FILING DATE June 22, 2000	PRIORITY DATE CLAIMED June 23, 1999	
TITLE OF INVENTION ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL MEASURING INTERFEROMETERS			
APPLICANT(S) FOR DO/EO/US Erlend RØNNEKLEIV			
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:			
<ol style="list-style-type: none"> 1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371 2. <input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371. 3. <input checked="" type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below. 4. <input checked="" type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31). 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2)) <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau). b. <input checked="" type="checkbox"/> has been communicated by the International Bureau. c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US) 6. <input type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)). <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto. b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4). 7. <input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)) <ol style="list-style-type: none"> a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau). b. <input type="checkbox"/> have been communicated by the International Bureau. c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired. d. <input checked="" type="checkbox"/> have not been made and will not be made. 8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)). 9. <input checked="" type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). 10. <input type="checkbox"/> An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)). 			
ITEMS 11. TO 20. below concern other document(s) or information included: <ol style="list-style-type: none"> 11. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98. 12. <input checked="" type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included. 13. <input checked="" type="checkbox"/> A FIRST preliminary amendment. 14. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment. 15. <input type="checkbox"/> A substitute specification. 16. <input type="checkbox"/> A change of power of attorney and/or address letter. 17. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825 18. <input checked="" type="checkbox"/> A second copy of the published international application WO 00/79335 A1 with PCT/ISA/210. 19. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4). 20. <input checked="" type="checkbox"/> Other items or information: PCT/IPEA/409; PCT/IB/308; PCT/IB/304; PCT/RO/101 			

U.S. APPLICATION NO. <u>10/013460</u> (If known, see 37 CFR 1.40)		INTERNATIONAL APPLICATION NO. PCT/NO00/00219		ATTORNEY DOCKET NO. 2036-200	
21. [X] The following fees are submitted: Basic National Fee (37 CFR 1.492)(a)(1)-(5): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report Not Prepared by EPO or JPO. \$ 1,040.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report has been prepared by the EPO or JPO \$ 890.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$ 740.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO but claims did not satisfy provisions of PCT Article 33(1)-(4) \$ 710.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) \$ 100.00 ENTER APPROPRIATE BASIC FEE AMOUNT =				<u>CALCULATIONS</u>	<u>PTO USE ONLY</u>
				\$ 1,040.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than [] 20 [] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	13 -20 =	0	X \$18.00	\$0	
Independent Claims	2 -3 =	0	X \$84.00	\$0	
Multiple dependent claim(s) (if applicable)			+ \$280.00	\$	
TOTAL OF ABOVE CALCULATIONS =				\$	
[X] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				\$520.00	
SUBTOTAL =				\$520.00	
Processing fee of \$130.00 for furnishing the English translation later than [] 20 [] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$	
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Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property				+	\$40.00
TOTAL FEES ENCLOSED =				\$ 560.00	
				Amount to be refunded	\$
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a. [X] Two checks in the amounts of \$520.00 and \$ 40.00 to cover the above fees are enclosed. b. [] Please charge my Deposit Account No. 02-2135 in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed. c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 02-2135. A duplicate copy of this sheet is enclosed. NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.					
SEND ALL CORRESPONDENCE TO:					
Customer No. 6449			<u>G.F. Rothwell</u> Signature		
G. Franklin Rothwell Rothwell, Figg, Ernst & Manbeck 555 13th St, N.W. Washington, D.C. 20004 Phone: 202/783-6040			<u>G. Franklin Rothwell, Reg.</u> Name		
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2036-2001-0243-001

<p align="center">IN THE UNITED STATES PATENT AND TRADEMARK OFFICE</p>	<i>Application Number</i>	PCT/NO00/00219
	<i>Filing Date</i>	June 22, 2000
	<i>First Named Inventor</i>	Erlend RØNNEKLEIV
	<i>Group Art Unit</i>	
	<i>Examiner Name</i>	
	<i>Attorney Docket Number</i>	2036-200
<p><i>Title of the Invention:</i> ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL MEASURING INTERFEROMETERS</p>		

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Please amend the above-identified application, preliminary to examination, as follows:

Amend claims 5,6, and 7, as shown on the following pages. Marked-up copies of the amended claims are attached to this amendment. Material inserted is indicated by underlining and material deleted is indicated by brackets.

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Clean Copy of Amended Claims

5. (Amended) Use of a method according to claim 1,
wherein the method is applied to interrogate a wavelength division multiplexed interferometer network.


6. (Amended) Use of a method according to claim 1,
wherein the method is applied to interrogate a time division multiplexed interferometer network.

7. (Amended) Use of a method according to claim 1,
wherein the method is applied to interrogate space division multiplexed interferometer networks.

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REMARKS

The present Amendment is made to eliminate the multiple dependent claims from the application. No new matter has been added by this Amendment and, accordingly, entry thereof is respectfully requested.

RESPECTFULLY SUBMITTED,					
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Attachments: Marked-Up Copies of Amendments

Amended Claims: Version with markings to show changes made

5. (Amended) Use of a method according to claim[s] 1,[2, 3, o r 4,]
wherein the method is applied to interrogate a wavelength division multiplexed interferometer network.
6. (Amended) Use of a method according to claim[s] 1,[2, 3, or 4,]
wherein the method is applied to interrogate a time division multiplexed interferometer network.
7. (Amended) Use of a method according to claim[s] 1,[2,3, or 4,]
wherein the method is applied to interrogate space division multiplexed interferometer networks.

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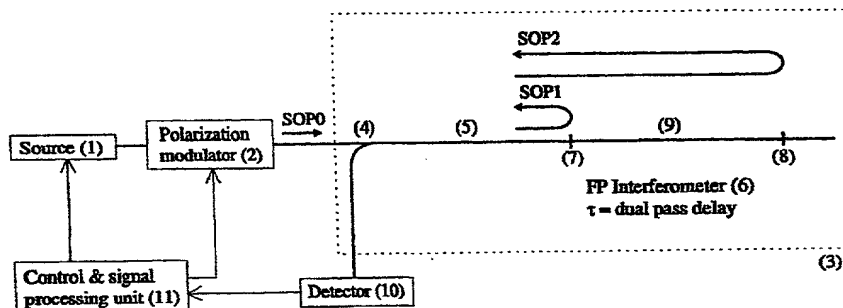
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL MEASURING INTERFEROMETERS



(57) Abstract: Method and assembly for sustained elimination or reduction of polarization induced signal fading in optical interferometer networks comprising at least two optical paths from an input port to an output port, the transmission delays of the paths differing by τ , an interrogation arrangement interrogating the optical phase differences between the paths, containing at least one optical source launching optical power into a port, a detector arrangement converting the optical power from an output port into electrical detector signals, and a control and signal processing unit capable of processing detector signals to determine the phase difference. The method comprising the steps of: altering the input polarization state produced by the source with a modulation frequency that is comparable to or higher than $1/(4\tau)$ receiving the optical signals at the detector arrangement providing a detector signal; processing the detector signal determining the phase difference between the optical signals.

ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL
MEASURING INTERFEROMETERS

This invention is related to a method and an assembly
for the elimination of polarization fading in unbalanced
5 optical measuring interferometers.

BACKGROUND OF THE INVENTION

An optical interferometer is an optical transmission
network that produces interference between different
portions of optical radiation that have traveled different
10 paths through the network. In an unbalanced optical
interferometer the time delay in the two optical paths are
different by an amount τ . The output intensity from such an
interferometer will have a periodic dependence called
fringes of the output intensity that is periodic versus the
15 interferometer phase delay $\phi = 2\pi\nu\tau$, where ν is the optical
frequency launched into the interferometer. Information
about the path delay difference, the input optical
frequency, or the input optical frequency spectrum may thus
be deduced from the output interference signal.

20 An optical interferometer network may also contain more
than one pair (or set) of paths from the input to the output
port. Different pairs (or sets) of paths may then be
interpreted as different interferometers. The interference
caused by individual interferometers may be interrogated
25 separately,

- a. by assigning a specific range of optical wavelengths,
thus employing a wavelength division multiplexing (WDM)
technique,
- b. by assigning a specific range of total transmission
30 time delay to the paths associated with each
interferometer, thus employing a time division
multiplexing (TDM) technique,
- c. or by assigning a specific combination of input and
output ports to the paths associated with each
35 interferometer, thus employing a space division
multiplexing (SDM) technique. An SDM system may for
instance be interrogated by using optical switches to

access different combinations of input and output ports sequentially, or by splitting the optical radiation from a single interrogation source into different interferometer sub-networks, and connecting one
5 detector to the output of each sub-network.

Network interrogation employing combinations of WDM, TDM and SDM is also possible.

The visibility or amplitude of the output fringes depends on the states of polarization (SOPs) of the two
10 interfering signals, which we will label SOP1 and SOP2. In many interferometers SOP1 and SOP2 will vary randomly with time due to changes in the input SOP or in the birefringence properties of the two optical pathways. The fringe
15 visibility is proportional to the projection of SOP1 onto SOP2. The reduction of fringe visibility with reduced projection of the SOPs is called polarization fading, and generally causes a reduced signal to noise ratio in the interferometer readout. Especially, the situation with SOP1
20 \perp SOP2 (orthogonal SOPs) causing total polarization fading with zero visibility should be avoided. When the fading is total, the interferometer output will not carry any information about v or t at all.

Several methods for reduction or elimination of the polarization fading problem are known. One known method uses
25 Faraday rotating mirrors, as disclosed by A.D. Kersey et. al. in ["Polarisation insensitive fibre optic Michelson interferometer", El. Lett., Vol. 27, pp. 518-19, 1991]. This method allows for a simple source and detection system, but it works only for the Michelson interferometer
30 configuration. Furthermore, the Faraday rotating mirrors may be expensive, space consuming, and sensitive to extreme thermal, electromagnetic and other environmental conditions.

Other known methods are based on active polarization control at the input, as disclosed by A. D. Kersey et. al.
35 in ["Optimization and Stabilization of Visibility in Interferometric Fiber-Optic Sensors Using Input-Polarization Control", J. of Lightwave Technol., Vol. 6, pp. 1599-1609, 1988], or the use of a polarizer combined with active polarization control at the output end, as disclosed by K.

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H. Wanser et. al. in ["Remote polarization control for fiber-optic interferometers ", Opt. Lett., Vol. 12, pp. 217-19, 1987]. In both cases the polarization controller is continuously adjusted to optimize the fringe visibility.

- 5 These techniques require relatively complex systems to provide feedback signals to the polarization controller, and in systems with spatial division multiplexing (SDM) or wavelength division multiplexing (WDM) of multiple sensors, individual polarization controllers for each sensor are
- 10 generally required. The polarization modulator used for the polarization control must be capable of modulating the SOP in three dimensions on the Poincarè sphere. This generally implies that the polarization modulators at least must be of the "dual stage" type. Dual stage polarization modulators
- 15 generally incorporate two independently adjustable birefringent elements, and are thus more complex and expensive than single stage modulators having only one adjustable birefringent element.

- Still other known methods are based on modulating the
- 20 input SOP between three states, as disclosed by A. D. Kersey et. al. in ["Input polarisation scanning technique for overcoming polarisation-induced signal fading in interferometric fiber sensors ", El. Lett., Vol. 24, pp. 931-33, 1988] and in [US Patent No. 4 932 783], or on the
- 25 use of three detectors at the output with three polarizers that are adjusted to monitor different polarization states, as disclosed by N. J. Frigo et. al. in ["Technique for elimination of polarisation fading in fibre interferometers", El. Lett., Vol. 20, pp. 319-20, 1984].
- 30 These techniques increase the complexity of the processing by requiring simultaneous processing of three fringe signals, especially in WDM systems where separate receivers are required for each WDM channel. They also increase the complexity of the hardware by either requiring a dual stage
- 35 polarization modulator, or three detectors and polarizers.

Another known method is based on the use of a pulsed source and a compensating interferometer which incorporates a polarization maintaining coupler, a standard coupler, and a polarization modulator, as disclosed by B. Y. Kim et. al.

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in [US Patent No. 5 173 743]. This method may be attractive when applied to time division multiplexed (TDM) ladder sensor networks. However, the compensating interferometer increases the complexity of the interrogation, and 3 dB of source power is lost in the output coupler from the compensating interferometer. If the network is not of the ladder type, another 3 dB of optical power will be effectively lost at the detector, since only one half of the detected pulses will carry useful information. Another problem with this method is that the readout phase from the interferometer is sensitive to birefringence changes in the lead fiber between the source and the interferometers.

One sensor configuration of special interest is that of a WDM fiber-optic interferometric sensor system employing two identical wavelength selective low reflectivity fiber Bragg grating reflectors to define the two paths of each sensor interferometer. For instance, a Fabry-Perot interferometer can be formed by writing two identical Bragg gratings into the core of a single optical fiber at different locations. Different reflection bands should be dedicated to each sensor, so that information about the individual sensors can be accessed by use of a multi-wavelength source at the network input producing coherent light at each sensor wavelength, and a wavelength division multiplexer at the network output, that directs the interference signal from each sensor to a dedicated detector.

OBJECTIVE

The main objective of the present invention is to provide a simple and practical method and assembly, with reduced complexity compared to existing techniques, which eliminates or reduces the probability for polarization induced fading in optical interferometers. This objective implies that the output signals from the interferometer always should carry the information required to determine the difference in optical path length, or optical phase, between two different paths through the interferometer.

A second objective of the present invention is to

provide a method and assembly which allows the readout interferometer phase to be insensitive to birefringence changes in the lead fiber between the source and the interferometer.

- 5 A third objective of the present invention is to provide a method and assembly which can be applied to interrogation of any types of unbalanced interferometer that do not contain polarization selective components, such as polarizers or polarization beam splitters. This class of
10 interferometers includes variants of the Fabry-Perot, Michelson, and Mach-Zender topologies. The method should also be applicable in interrogation systems where a pulsed source and a compensating interferometer is used to compensate out the imbalance of the interrogated
15 interferometer(s).

- A fourth objective of the present invention is to provide a method and assembly which can be applied to interrogation of wavelength division multiplexed (WDM), space division multiplexed (SDM), and time division
20 multiplexed (TDM) interferometer networks, including TDM ladder networks.

- A specific objective of the present invention is to provide a method and assembly which can be applied to interrogation of fiber optic wavelength division multiplexed
25 sensor systems employing wavelength selective Bragg reflectors in the sensing interferometers and a multi-wavelength source, which requires only one polarization modulator for the entire system, and only one detector dedicated to the monitoring of each sensor.

- 30 A general objective of the present invention is to provide a method and assembly that overcomes limitations set by other known methods.

SUMMARY OF THE INVENTION

- The objective of the invention is achieved with a
35 method having features as stated in claims 1 and 8. Further features are stated in the dependent claims.

The main part of the invention is characterized in that the polarization state of the optical power launched into an

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interferometer network is modulated at a frequency comparable to or higher than the inverse of the difference in transmission time delay between the two optical paths through the interferometer. A control and signal processing unit extracts several interference signals detected at the output of the interferometer network in at least two time slots, that are positioned in time at certain time delays (or phases) relative to the input polarization modulation period. The time slots should be chosen such that the two optical signals interfering at the output port after having traveled the two paths through the interferometer, originate from different combinations of input polarization states in each time slot, and such that total polarization fading of the interference visibility never will occur simultaneously in all time slots. Minimization of the sensitivity of the readout interferometer phase to birefringence changes in the path from the interrogating optical source to the interferometer may be achieved by modulating the input polarization between two orthogonal polarization states and by processing signals from four distinct time slots.

DETAILED DESCRIPTION OF THE INVENTION

The invention will be described below with reference to the accompanying drawings illustrating the invention by way of examples.

- 25 Fig. 1 illustrates a preferred embodiment of this invention, including the interrogated interferometer network (3) including a Fabry-Perot interferometer.
- Fig. 2 illustrates a typical evolution of the input and
30 output states of polarizations (SOPs) versus time.
- Fig. 3 illustrates alternative embodiments of the interferometer network (3) in Fig. 1, incorporating a Michelson interferometer in Fig. 3 (a) and a Mach-Zender interferometer in Fig. 3
35 (b).
- Fig. 4 illustrates an alternative embodiment of the invention, demonstrating interrogation of multiple wavelength division multiplexed interferometers.

In the preferred embodiment of this invention, illustrated in Fig. 1, an optical source (1) launches coherent optical radiation into the fiber-optic sensor network (3) through a polarization modulator (2). The sensor network (3) consists of an input-output optical coupler (4) with a 50% power splitting ratio, a lead fiber (5) and a low finesse Fabry-Perot (FP) interferometer (6) consisting of two reflectors (7,8) and a fiber delay line (9) with dual-pass delay τ . The power reflectivities of (7) and (8) should preferably be small ($<10\%$), allowing multiple mirror reflections to be neglected. The output power from the network (3) is guided to a photo-detector, and the resulting analog electrical signal is transferred to the analog-to-digital conversion interface of a control & signal processing unit (11), which is responsible for processing the detected signals electronically to extract the interferometer phase information, and for transferring this information in a suitable form to the end user.

The control & signal processing unit (11) also controls the polarization modulator (2) and causes the input polarization state SOP0 launched into (3) to switch between two orthogonal states, denoted SOP0a and SOP0b in Fig. 2. The polarization switching period should equal 4τ , and the duty-cycle of the modulation should be 50%, as illustrated by the top curve in Fig. 2. The coupler (4), the lead fiber (5), the interferometer fiber (9), and the reflectors (7,8) should have negligible polarization dependent losses. The latter condition implies that the polarization states SOP1 and SOP2 reflected from (7) and (8), respectively, and interfering at the left hand side of (7) in Fig. 1, will also both be switching between two orthogonal states, denoted SOP1A, SOP1B, SOP2A, and SOP2B in Fig. 2. SOP1A and SOP1B may then generally be written in a Jones-vector notation as

$$SOP1A = \vec{A} = K_1 \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha) e^{i\gamma} \end{bmatrix} \quad SOP1B = \vec{B} = K_1 \begin{bmatrix} \cos(\alpha) e^{-i\gamma} \\ \sin(\alpha) \end{bmatrix}$$

where the vector elements are chosen to represent the projections of the fields onto the orthogonal eigen-polarization states of the interferometer. By the interferometer eigen-polarization states we mean the

5 orthogonal output SOPs generated when the SOP0 is adjusted so that SOP1 = SOP2. K_1 depends on the source power, and the losses in the transmission through (4,5,9) and in the reflections (7,8), while α and γ are angles that depend on the birefringence properties of the lead fiber (5).

10 The chosen polarization projection states allow SOP2A and SOP2B to be written on the form

$$SPO2A = \vec{J}\vec{A} = K_2 e^{i\phi} \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha) e^{i\gamma+\theta} \end{bmatrix} \quad SPO2B = \vec{J}\vec{B} = K_2 e^{i\phi} \begin{bmatrix} \cos(\alpha) e^{-i\gamma} \\ \sin(\alpha) e^{i\theta} \end{bmatrix}$$

where the Jones matrix

$$\vec{J} = e^{i\phi} \begin{bmatrix} 1 & 0 \\ 0 & e^{i\theta} \end{bmatrix} \quad (1)$$

essentially describes difference between the SOP changes from SOP0 to SOP1 and that from SOP0 to SOP2. $\phi = 2\pi\nu\tau$ is the
15 interferometer phase that we want to measure, ν is the optical frequency, and θ is the birefringent phase-shift between the eigen-polarization states of the interferometer. K_2 depends on losses in the transmissions and reflections of the system.

20 The two lower curves in Fig. 2 illustrate the switching of SOP1 and SOP2. A periodic pattern consisting of 4 time slots can be observed, where:

- SOP1A interferes with SOP2A in slot1,
- SOP1B interferes with SOP2A in slot2,
- 25 - SOP1B interferes with SOP2B in slot3,
- SOP1A interferes with SOP2B in slot4.

The interference power will be composed by one term that depends on ϕ, θ, γ , and α , and one term that is independent on

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these parameters. The power from each time slot n will produce an electrical signal, S_n at the detector output, which is proportional to the interference power. Based on the given conditions, it can be shown that

$$\begin{aligned} S_1 &= 2K_3 \operatorname{Re}(\vec{A}^+ \vec{J}\vec{A}) = a \cos(\phi_1) \\ S_2 &= 2K_3 \operatorname{Re}(\vec{B}^+ \vec{J}\vec{A}) = a \cos(\phi_2) \\ S_3 &= 2K_3 \operatorname{Re}(\vec{B}^+ \vec{J}\vec{B}) = a \cos(\phi_3) \\ S_4 &= 2K_3 \operatorname{Re}(\vec{A}^+ \vec{J}\vec{B}) = a \cos(\phi_4) \end{aligned} \quad (2)$$

- 5 where K_3 accounts for the detector responsivity and losses in (4,5), superscript $+$ indicates conjugate transpose,

$$\begin{aligned} \phi_1 &= \phi + \theta + \varphi \\ \phi_2 &= \phi + \theta/2 + \gamma - \pi/2 \\ \phi_3 &= \phi - \theta \\ \phi_4 &= \phi + \theta/2 - \gamma - \pi/2 \end{aligned} \quad , \text{ and } a^2 + b^2 = K_1 K_2 K_3^2. \quad (3)$$

ϕ is a function of θ and α .

- The control & processing unit extracts the signals S_1 through S_4 and processes them to determine the phases ϕ_1 through ϕ_4 . Note that the detected signals are delayed relative to the control signals supplied to the polarization modulator. Some calibration of the input slot timing is therefore required. Several methods are known for phase reconstruction without ambiguity from interference signals, as disclosed for instance by I. J. Bush in ["High performance interferometric demodulation techniques", SPIE Proc., Vol. 1795, pp. 412-20, 1992]. Generally, these methods require means for modulating the interference phase to generate in-phase and quadrature information from the interference fringes. In the preferred embodiment of the present invention this can be achieved by modulating the phase of the source radiation at a frequency that is an odd harmonic of $1/(4\tau)$.

- We see from (Eq. 2) that the detected fringe amplitudes equal a in slots 1 and 3, and b in slots 2 and 4. Since $a^2 + b^2 = K_1 K_2 K_3^2$ according to (Eq. 3), there can never be fading

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simultaneously in two neighboring time slots, and the sum of the signal to noise ratios of two neighboring time slots, limited by the fringe amplitude, will be independent on the birefringence parameters θ , γ , and α . Thus, the main objective of the present invention is satisfied.

It remains to combine the information carried by ϕ_1, ϕ_2, ϕ_3 , and ϕ_4 into one single estimate for the interferometer phase delay, which according to (Eq. 1) is ϕ for one eigen-polarization and $\phi+\theta$ for the other eigen-polarization. In the preferred embodiment, the estimator

$$\Phi = \frac{a^2(\phi_1 + \phi_2) + b^2(\phi_3 + \phi_4)}{a^2 + b^2} \quad (4)$$

is computed by the control & processing unit to estimate the interferometer phase delay. By combining (Eq. 3) and (Eq. 4) we see that Φ in the absence of noise equals $\phi+\theta/2$, which is exactly the mean of the two eigen-polarization phase delays. Φ is independent on the birefringence parameters γ and α of the lead fiber, and thus the second objective of the present invention is satisfied. The weighting in (Eq. 4) of $\phi_1+\phi_2$ and $\phi_3+\phi_4$ by a^2 and b^2 , respectively, ensures that the signal to noise ratio of the estimator always will be close to a maximum.

The present invention may be implemented for interrogation of any types of unbalanced interferometer networks that do not contain polarization selective components such as polarizers or polarization beam splitters. As one example, Fig. 3 (a) illustrates a network incorporating a Michelson interferometer, which may replace the network (3) in Fig. 1 in a second embodiment of the present invention. SOP0 is launched into the input/output coupler (4) and the lead fiber (5), having the same functions as in Fig. (1). The Michelson interferometer (12) is formed by an optical coupler (13) splitting the optical power from (5) into two delay arms, with reflectors (14,15) positioned at different distances from (13) so that the dual path time delays experienced by the two reflected signals

recombined in (13) differ by τ . SOP1 and SOP2 in this case refer to the polarization states recombined in (13) after returning from the short delay arm with reflector (14) and the long delay arm with reflector (15), respectively.

- 5 As another example, Fig. 3 (b) illustrates a network incorporating a Mach-Zender (MZ) interferometer, which may replace the network (3) in Fig. 1 in a third embodiment of the present invention. This system has separate input (16) and output (22) lead fibers. SOP0 is launched into (16). The
- 10 MZ interferometer (17) is formed by an optical coupler (18) splitting the optical power from (16) into two delay arms (19,20). The signals emerging from (19) and (20) are combined in a second optical coupler (21). The single pass time delays between (18) and (21) through (19) and (20)
- 15 should differ by τ . SOP1 and SOP2 in this case refer to the polarization states entering (21) from the short (19) and long (20) arms, respectively.

- Fig. 4 illustrates a fourth embodiment of the present invention capable of wavelength division multiplexing of
- 20 several wavelength selective interferometers. In the illustrated example, a multi-wavelength source (23) is used, launching coherent radiation at three sensor interrogation wavelengths λ_1 , λ_2 , and λ_3 through the polarization modulator (2) into the interferometer network (24). The input
- 25 polarization of all wavelengths is switched simultaneously between orthogonal states, in the same way as explained for SOP0 in the preferred fifth embodiment of the present invention. The network contains an input/output coupler (4), a lead fiber (5) and three FP-interferometers with
- 30 approximately equal dual-pass delay τ . Each FP-interferometer consists of two identical Bragg gratings, denoted (25), (26) or (27), causing a weak reflection in a narrow band around the respective sensor interrogation wavelength λ_1 , λ_2 , or λ_3 . Each sensor grating pair should
- 35 produce negligible reflections at the interrogation wavelengths of the other sensors. A wavelength division demultiplexer (28) is connected to the output branch of (4), distributing the interference signals from the different

interferometers to different detectors (29, 30, 31). The control & processing unit (32) processes the three detector signal sequences in parallel in the same way as explained for the single processing channel in the first preferred embodiment, to extract the individual interference phases of the three interferometers and present this information for the end user.

The network (23) in Fig. 4 can be interrogated by a time division multiplexing (TDM) approach using the present invention, provided that all reflectors reflect the same wavelength, i.e. either $\lambda_1 = \lambda_2 = \lambda_3$, or the gratings must be replaced with broad-banded reflectors, and that the dual pass delays from the input/output (4) to the beginning of the different interferometers all are separated by at least in the order of 3τ . In this case, a possible fifth embodiment of the present invention uses a pulsed single wavelength source at wavelength λ_1 , and only one detector without any wavelength demultiplexer in front, like the detector (10) in Fig. 1. The source and polarization modulator produces pulses with a duration of minimum 2τ , with polarization state switching between orthogonal polarizations within each pulse at a frequency that is an odd harmonic (or multiple) of $1/(4\tau)$ and which is higher than the inverse pulse duration, like illustrated for SOP0 in Fig. 2. The detected signal will consist of one time sequence for each pulse transmitted from the source, each sequence containing at least four time-slots originating from each sensor interferometer. The time slots contain information about the interference phases of individual sensors, encoded in the same way as for the output time-slot signals described in the first preferred embodiment. The control and processing unit may thus extract the interference phases by separating, identifying and processing the information originating from each sensor in the same way as described for the first preferred embodiment.

A special case of TDM interferometer networks are ladder interferometer networks, with geometries of the type

described in [US Patent No. 5 173 743, Fig.1, items (26),
(27 a, b, c, d), (28), and (31 a, b, c, d)]. In the ladder
networks, the input to output delay of a number N of
interferometer arms are equally spaced by the amount τ , and
5 all paths, except for two, are thus part of two
interferometers at the same time. The current invention can
be used for interrogation of such ladder networks,
including a compensating interferometer with imbalance τ
placed after the source, as illustrated in [US Patent No. 5
10 173 743, Fig.1, items (20, 21, 22, 23, 25)]. Each pulse from
the source should have duration equal to τ , and will thus be
split into two by the compensating interferometer. The
polarization modulator can be placed between the
compensating interferometer and the network. Polarization
15 maintaining fibers and couplers should be used in the
compensating interferometer to ensure that the polarization
states of the two consecutive pulses emerging from the
compensating interferometer will be switching between
identical pairs of orthogonal polarization states.
20 Alternatively, an imbalanced Michelson interferometer with
Faraday-rotating mirrors, and otherwise standard fibers and
couplers, may be used as the compensating interferometer.

The current invention may be used for interrogation of
such ladder networks, without the inclusion of any
25 compensating interferometer. The duration of each pulse from
the source should in this case be close to 2τ .

Although coherent sources have been assumed in all the
previous examples, the present invention can also be used in
a white-light interferometer that are interrogated by
30 scanning the path-imbalance of a compensating
interferometer.

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C l a i m s

1. Method for sustained elimination or reduction of polarization induced signal fading in optical interferometer networks comprising

at least two optical paths from an input port to an output port, the transmission delays of the at least two paths differing by an amount of time τ ,

an interrogation arrangement interrogating the optical phase differences induced between optical waves having traveled the said paths,

said arrangement containing at least one optical source launching optical power into said input port, a detector arrangement converting the optical power received from said output port into electrical detector signals, and a control and signal processing unit capable of processing said detector signals to determine the said phase difference,

the method comprising the steps of:

- altering the input polarization state produced by the source with a modulation frequency that is comparable to or higher than $1/(4\tau)$,
- receiving the at least two optical signals having traveled said at least two paths at said detector arrangement providing a detector signal,
- processing said detector signal at said control and signal processing unit determining the phase difference between the optical signals having traveled said paths.

2. Method according to claim 1, in which the input polarization state produced by the source changes between a first and a second state (SOP0A, SOP0B), and in which four interference signals (i, ii, iii, iv) being separated in time, representing interference between polarization states at said output port that originate from the transmission of

- (i) SOP0A through both the first and the second interferometer path,
- (ii) SOP0B through the first and SOP0A through the

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(iii) SOP0B through both interferometer paths, and
(iv) SOP0A through the first and SOP0B through the second interferometer path,
respectively, are extracted by said control and signal processing unit and further processed to produce estimates for the interference phases of the four interference signals (i,ii,iii,iv).

3. Method according to claim 2, wherein the interference visibilities or fringe amplitudes of the four interference signals (i,ii,iii,iv) are calculated.

4. A method according to claim 3, wherein SOP0A and SOP0B are orthogonal polarization states, and a first improved phase estimate, called Φ_1 , is calculated as the average of the two said interference phase estimates produced from (i) and (iii), and a second improved phase estimate, called Φ_2 , is calculated as the average of the two said interference phase estimates produced from (ii) and (iv), and a combined phase estimate is calculated as a weighted average of Φ_1 and Φ_2 , where the ratio between the weighting of Φ_1 and the weighting of Φ_2 is decided from the relation between the said interference visibilities or fringe amplitudes.

5. Use of a method according to claims 1, 2, 3, or 4, wherein the method is applied to interrogate a wavelength division multiplexed interferometer network.

6. Use of a method according to claims 1, 2, 3, or 4, wherein the method is applied to interrogate a time division multiplexed interferometer network.

7. Use of a method according to claims 1, 2, 3, or 4, wherein the method is applied to interrogate space division multiplexed interferometer networks.

8. Assembly for sustained elimination or reduction of polarization induced signal fading in optical interferometer networks comprising:

at least two optical paths from an input port to an output port, the transmission delays of the at least two paths differing by an amount of time τ ,

an interrogation arrangement interrogating the optical phase differences induced between optical waves having traveled the said paths,

said arrangement containing at least one optical source launching optical power into said input port, a detector arrangement converting the optical power received from said output port into electrical detector signals, and a control and signal processing unit capable of processing said detector signals to determine the said phase difference,

said optical source comprising polarization means for altering the input polarization state produced by the source with a modulation frequency that is comparable to or higher than $1/(4\tau)$,

9. Assembly according to claim 8, wherein the input polarization state produced by the source is adapted to emit alternately a first and a second state (SOP0A, SOP0B) through two interferometer paths resulting in four interference signals (i, ii, iii, iv) being separated in time, representing interference between polarization states at said output port originating from the transmission of

- (i) SOP0A through both the first and the second interferometer path,
- (ii) SOP0B through the first and SOP0A through the second interferometer path,
- (iii) SOP0B through both interferometer paths, and
- (iv) SOP0A through the first and SOP0B through the second interferometer path,

respectively, said control and signal processing unit being adapted to extract and further process said interference

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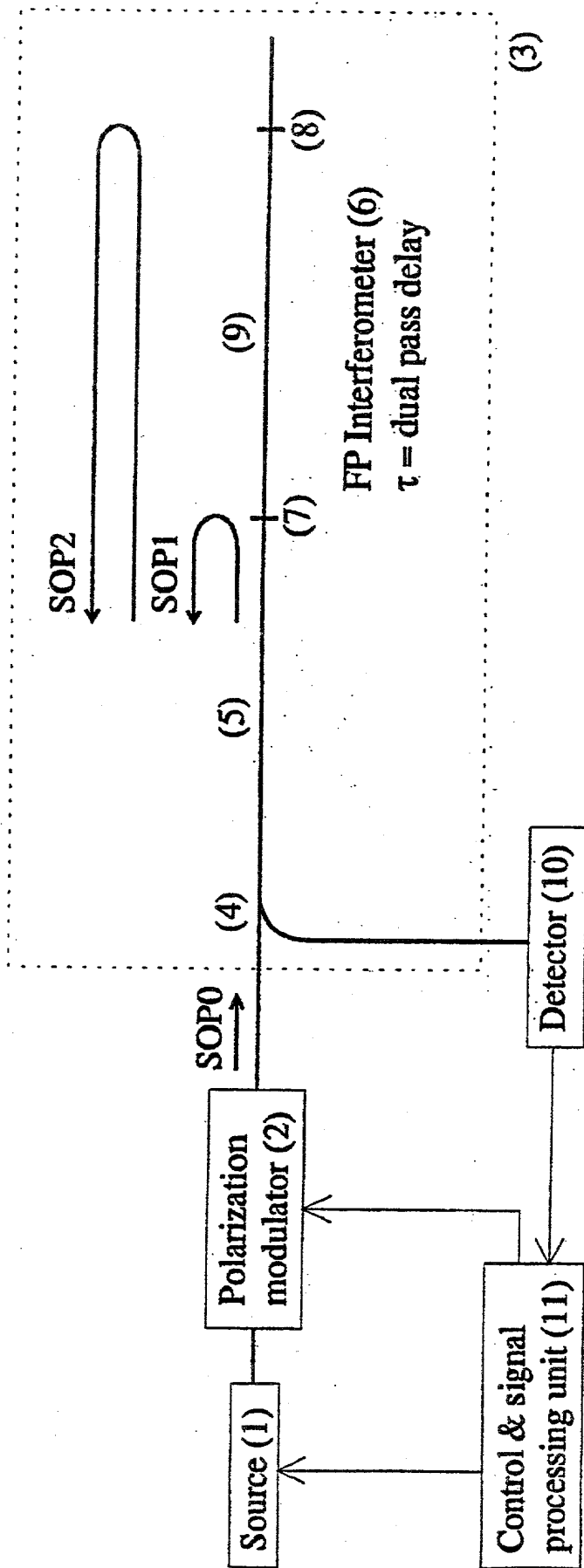


Fig. 1

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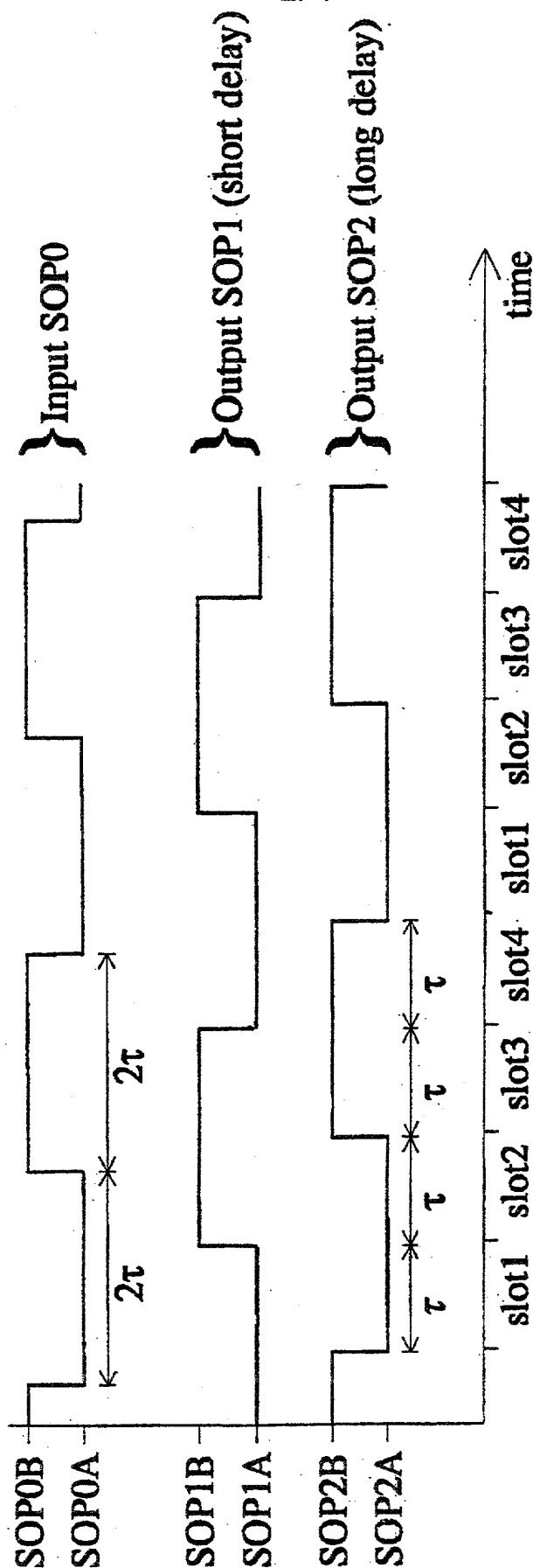


Fig. 2

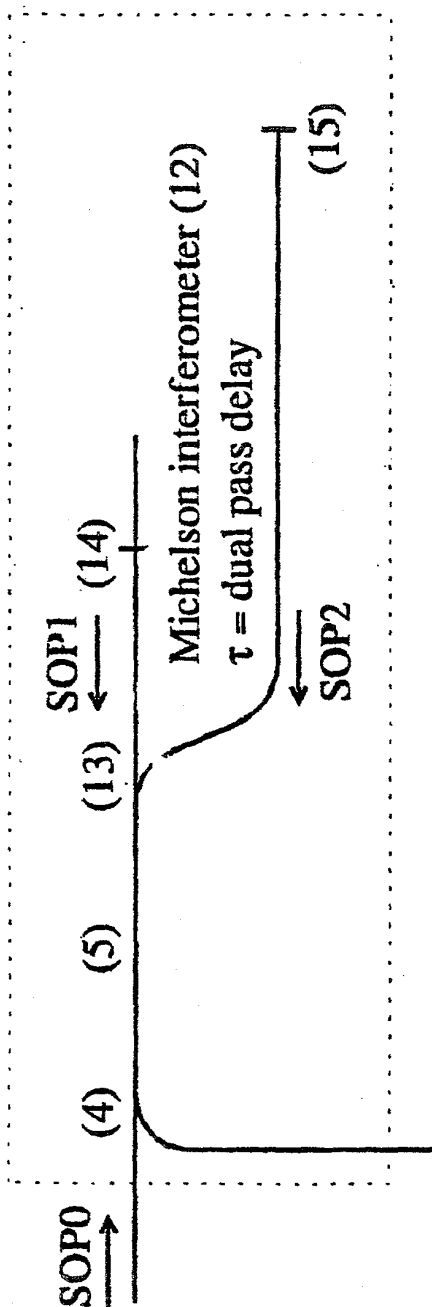


Fig. 3 (a)

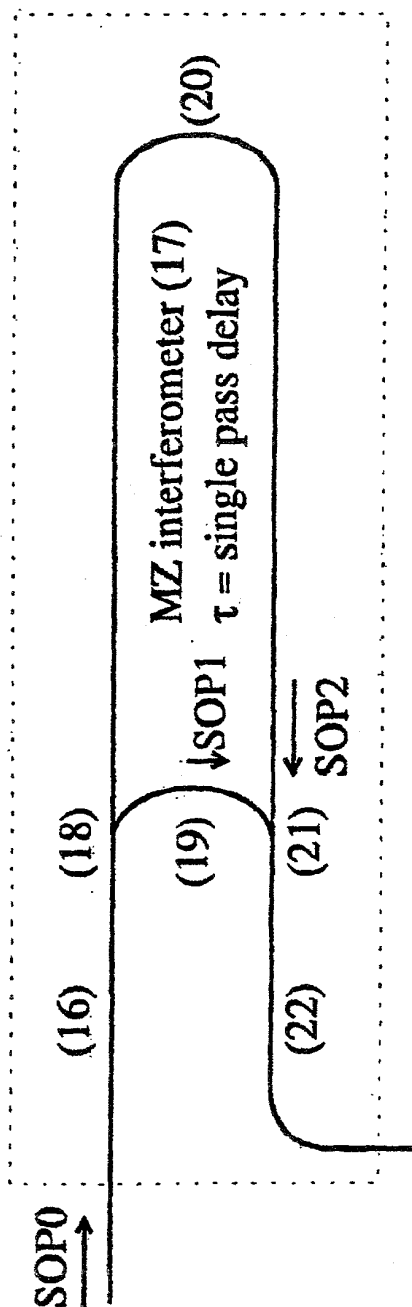


Fig. 3 (b)

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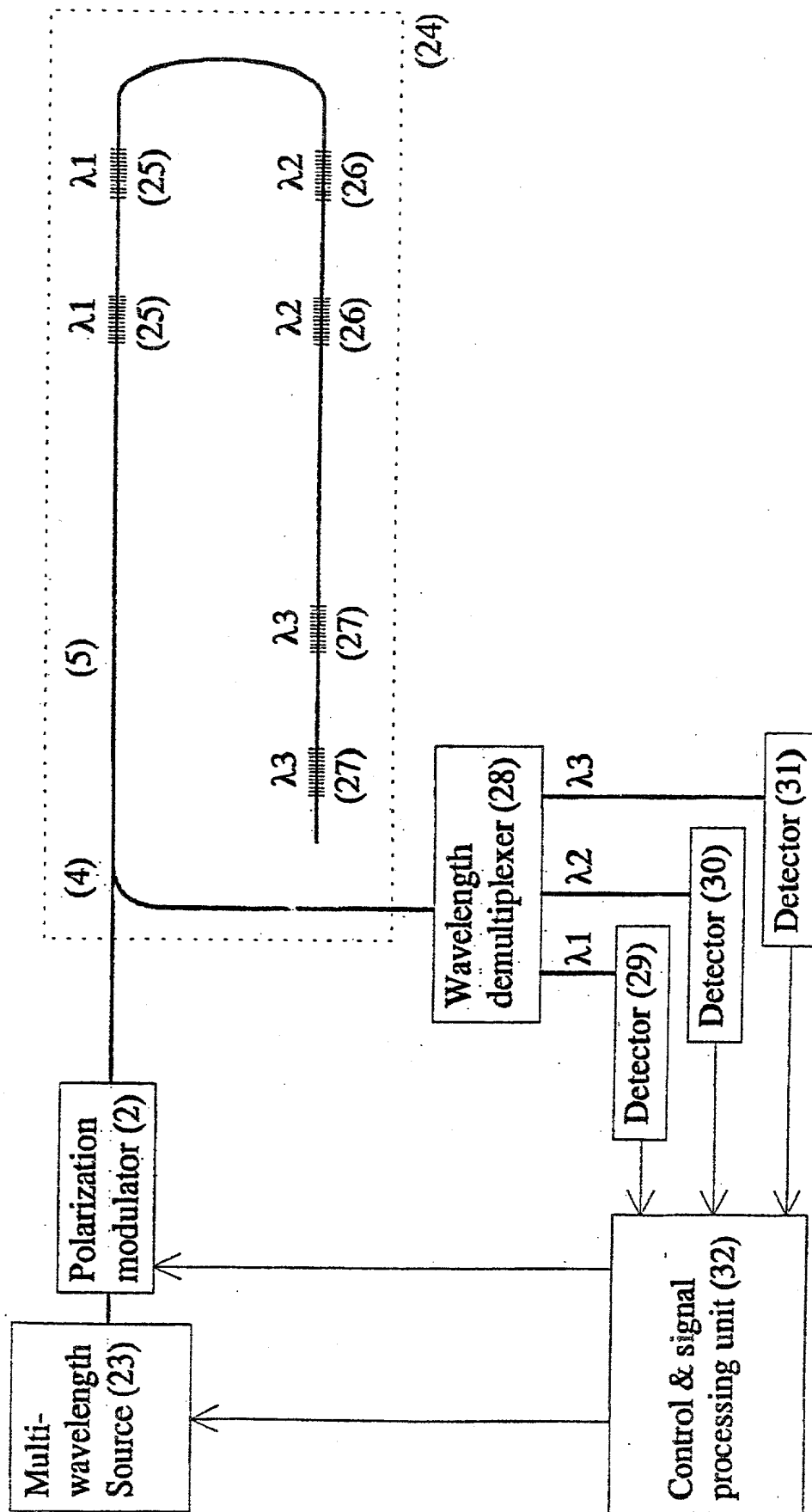


Fig. 4

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Optoplan I

**Declaration and Power of Attorney
For Patent Application
(Sole/Joint)**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I verily believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought, on the invention entitled ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL MEASURING INTERFEROMETERS

the specification of which (Check One)

___ is attached hereto.

OR

X was filed on June 22, 2000 as

[] Application Serial No. _____

[X] International Application No. PCT/ NO00/00219

and was amended on _____

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application..

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT application having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Priority Claimed

<u>1999.3135</u> (Number)	<u>Norway</u> (Country)	<u>June 23, 1999</u> (Day/Month/Year Filed)	Yes: <u>X</u> No: ___
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	Yes: ___ No: ___
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	Yes: ___ No: ___

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below:

APPLICATION NUMBER: _____ FILING DATE: _____
APPLICATION NUMBER: _____ FILING DATE: _____

10018450-032303

I or we hereby appoint the registered practitioner(s) associated with **Customer Number 6449** to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. Direct all correspondence about the application to **Customer Number 6449**.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Name of Sole or First Inventor		<input type="checkbox"/> A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any]) <u>Erlend</u>		Family Name or Surname <u>RØNNEKLEIV</u>	
Inventor's Signature <u>Erlend Rønnekleiv</u>		Date <u>16. Nov. 2001</u>	
Residence (City, State, Country) <u>Trondheim, Norway</u> <u>NOX</u>		Citizenship <u>Norwegian</u>	
Mailing Address (Street, City, State, Zip or Postal Code, Country) <u>Sig. Jorsalfars v. 23b, N-7052 Trondheim, Norway</u>			
Name of Second Inventor		<input type="checkbox"/> A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			
Name of Third Inventor		<input type="checkbox"/> A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			
Name of Fourth Inventor		<input type="checkbox"/> A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			

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Uptoplan 1

Attorney Docket No. _____

**Declaration and Power of Attorney
For Patent Application
(Sole/Joint)**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I verily believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought, on the invention entitled ELIMINATION OF POLARIZATION FADING IN UNBALANCED OPTICAL MEASURING INTERFEROMETERS

the specification of which (Check One)

___ is attached hereto.

OR

X was filed on June 22, 2000 as

[] Application Serial No. _____

[X] International Application No. PCT/ NO00/00219

and was amended on _____

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application..

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT application having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Priority Claimed

<u>1999.3135</u> (Number)	<u>Norway</u> (Country)	<u>June 23, 1999</u> (Day/Month/Year Filed)	Yes: <u>X</u> No: _____
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	Yes: _____ No: _____
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	Yes: _____ No: _____

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below:

APPLICATION NUMBER: _____ FILING DATE: _____
APPLICATION NUMBER: _____ FILING DATE: _____

20230909-033302

I or we hereby appoint the registered practitioner(s) associated with Customer Number 6449 to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. Direct all correspondence about the application to Customer Number 6449.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Name of Sole or First Inventor		___ A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any]) <u>Erlend</u>		Family Name or Surname <u>RØNNEKLEIV</u>	
Inventor's Signature <u>Erlend Rønnekleiv</u>		Date <u>16. Nov. 2001</u>	
Residence (City, State, Country) <u>Trondheim, Norway</u> NOX		Citizenship <u>Norwegian</u>	
Mailing Address (Street, City, State, Zip or Postal Code, Country) <u>Sig. Jorsalfars v. 23b, N-7052 Trondheim, Norway</u>			
Name of Second Inventor		___ A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			
Name of Third Inventor		___ A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			
Name of Fourth Inventor		___ A petition has been filed for this unsigned inventor.	
Given Name (first and middle [if any])		Family Name or Surname	
Inventor's Signature		Date	
Residence (City, State, Country)		Citizenship	
Mailing Address (Street, City, State, Zip or Postal Code, Country)			